INTERNATIONAL JOURNAL OF TECHO-ENGINEERING
ISSN : 2057-5688

Optimum Design of Power Converter Current Controllers in Power Electronics combined Power Systems

[1]T Maniram [2]B Madhava [3]K Srinivas [4]T. Rama pichiah
[1]PG student, department of EEE in SSN Engineering College Ongole.
[2]Assistant professor, department of EEE in SSN Engineering College Ongole.
[3]HOD, department of EEE in SSN Engineering College Ongole.
[4]Principal, SSN Engineering College Ongole.

ABSTRACT

Large-scale deployment of Renewable Energy Sources (RES) has led to significant generation shares of variable generation in power systems worldwide, which causes challenges in frequency control and system stability. In this project, a novel virtual inertia and damping controller for converters in power systems with high share of RES is proposed. The controller is designed for both single converter and uniform low inertia systems, where the combined effect of the adaptive inertia and damping on the system frequency response is analyzed. In a large-scale power electronic system such as a wind farm, the mutual interactions between the power converter controllers and passive components may lead to instability problems or undesired dynamic response. This paper presents an optimum parameter design procedure for the power converter controllers in a power electronic system in order to guarantee a stable operation and to guarantee an acceptable dynamic response. In the approach, first, all oscillatory modes are calculated by a multi-input multi-output (MIMO) transfer function matrix of the power system; then, a multi-objective optimization procedure based on the genetic algorithm (GA) is presented to place the modes in the desired locations in order to increase the stability margin and to improve the dynamic response. The proposed controller is integrated into a state-of-the-art converter control scheme and verified through MATLAB/SIMULINK simulations.

I. INTRODUCTION

Power converters are electronic circuits associated to the conversion, control, and conditioning of electric power. The power range can be from milliwatts, mobile phone, for example, to megawatts, in electric power transmission systems. Reliability of the power converters become a key industrial focus. Electronic devices and control circuit must be highly robust in order to achieve a high useful life. A special accent must be set on the total efficiency of the power electronic circuits. Firstly, because of the economic and environmental value of wasted power and, secondly, because of the cost of energy dissipated that it can generate. Even a small improvement in converter power efficiency translates to improved profitability of the investment in the electronic market. Among all electronic converters, the most common technology is switched-mode power converters (SMPC). They convert the voltage input to another voltage signal, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. This switched-mode conversion has a particular interest due to the fact that it can switch at high frequency in a very efficient way. Power is controlled (even modified) by controlling the timing that the electronic switches are “on” and “off”.

A much greater emphasis is required on achieving high-power efficiency in low-power level electronic technology, since few low-power circuits can tolerate a power efficiency less than 85%. Converters are used in these circuits in order to change the supply voltage in the blocks of the System on Chips (SoCs) according to performance requirements, for power efficiency reasons. Research have been focused on developing electronic circuits that can be employed as switches. e.g. approximating ideal closed or open switches, as the Vdd-hopping converter. Power converters control the flow of power between two systems by changing the character of electrical energy: from direct current to alternating current, from one voltage level to another voltage, or in some other way. Here, some important way to classify the power converters are described. The aim of this section is not to make a rigorous converter classification, either to make a state of the art, because it is not the purpose of this thesis. It is only desired to understand some properties of these kind of circuits. DC-DC power converters have a very large presence in all kind of electronic circuits, from industrial applications (spacecraft power systems, DC motor drives, telecommunication equipment) to personal applications (PCs, office equipment, electrical appliance). These systems provide a regulated DC voltage level (Vo) from an unregulated DC voltage level (Vin).

High efficiency is the most important requirement for DC-DC converters in a wide range of load power, since it directly affects the battery lifetime. It can be achieved using ‘switched-mode’. A switched-mode power converter (SMPC) is characterized by rapidly switching on and off some devices, transferring a rate of energy from the input to the output. This rate of energy is controlled by a duty cycle1 to minimize the dissipated energy. The switching effect is achieved by transistors, which dissipates little power when it is outside of its active region. In addition, SMPCs have an inductor, whose main function is to limit the current slew rate through the power switch. This action help to limit the otherwise high peak current. Moreover, the inductor stores the energy, which can be recovered in the discharge phase. This approach is also used in alternating current (AC) applications.

II. SYSTEM MODELING

A simple block-diagram of a grid-connected converter with an inner control loop is shown in Fig. 4.1(a), where G_{cont-k} is the current controller and $G_{delay-k}$ is the delay of the digital control implementation. Fig. 4.1(b) shows the block diagram of the current closed-loop control system, where the PoC voltage (V_{PoC-k}) and the current reference (I_{ref-k}) are the inputs and the grid current (I_{g-k}) is the output. Based on a grid-connected converter can be modeled by an ideal current source along with a parallel active admittance (Norton equivalent circuit) as shown in Fig. 4.1(c). This paper focuses on optimum design of the current controller, which is fast and a high-bandwidth controller. Therefore, the outer power controllers and grid synchronization loops are neglected as they are too slow to have influence on current controller dynamics.

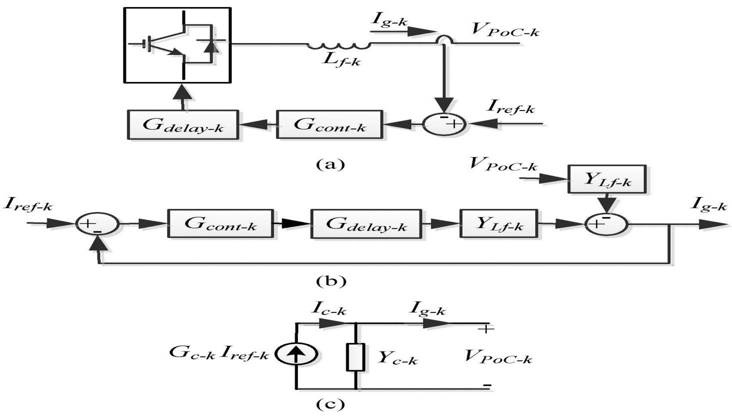


Fig. 1.Grid-connected converter with the inner control loop and its equivalent circuit. (a)Grid-connected converter with the inner control loop. (b) Closed-loop control of grid current. (c) Norton equivalent of the converter.

By modeling of every passive element and active element (power electronic converters) as Norton equivalent circuit, the current–voltage relationships in a power electronic system can be obtained by the nodal admittance matrix as given in (5 shown at the bottom of this page). Therefore, in order to guarantee the stability, an inequality constraint $H(\mathbf{x})$ is considered in GA algorithm to set the real part of Pc smaller than zero. The threshold value for stability is zero mathematically. However, because of the round off errors of floating-point computations and the grid variations, the threshold value should be considered a value larger than zero to be robust. The optimum parameter vector (**x**) includes the filter parameters to have more freedom degrees and to optimize the system ideally. In a case, if the filter parameters cannot be redesigned, the vector includes only the controller parameters. In this case, there are less freedom degrees for the optimization and may not optimize the system ideally. In a power electronics based systems, low-frequency modes are related to the power converter controllers and the high frequency modes are more related to the cables and transformers. As the switching frequency (*fs*) is considered to be 2.5 kHz, the maximum logical bandwidth for the current controller would be around 500 Hz (*fs*/5). Therefore, In order to guarantee the desired dynamic performance of the power converters in a power electronic system, an objective function is considered to set the damping ratios of all low-frequency modes close to 0.8; in fact, the objective function is to minimize $F(x)$.

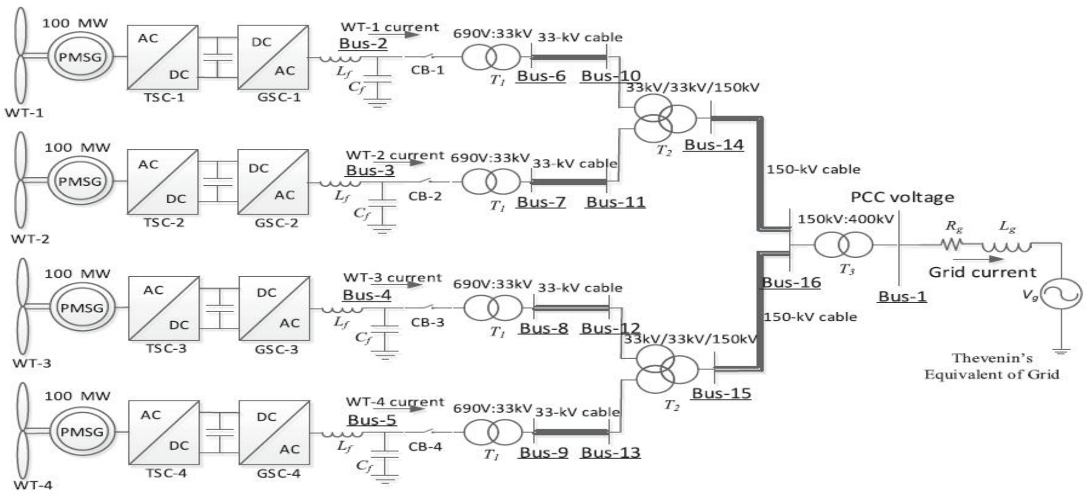


Fig.2. 400-MW wind farm, which is studied for the proposed optimum controller design method.

The effectiveness of the proposed optimized design approach is studied for a 400-MW wind farm with 100-MW aggregated strings, as shown in Fig. 4.2. Under the nominal operation, the current on the feeder is increasing towards the collector bus as the number of the WTs is also increasing. Therefore, a closer cable to the collector bus should have a larger cross-section than a farther cable. Consequently, three different cables (95 mm2 cable, 240 mm2 cable, and 400 mm2 cable) carry the feeder current. Five WTs of 6.7 MW on each feeder can be aggregated by one 33-MW WT. Since the dc-link is almost constant, the dynamics of the turbine-side converters (TSCs) can be neglected.

INTERNATIONAL JOURNAL OF TECHO-ENGINEERING

ISSN : 2057-5688

III. SIMULATION RESULTS

The effectiveness of the proposed optimized design approach is studied for a 400-MW wind farm with 100-MW aggregated strings, as shown in Figure.

CASE-A: DYNAMIC RESPONSE OF GSC

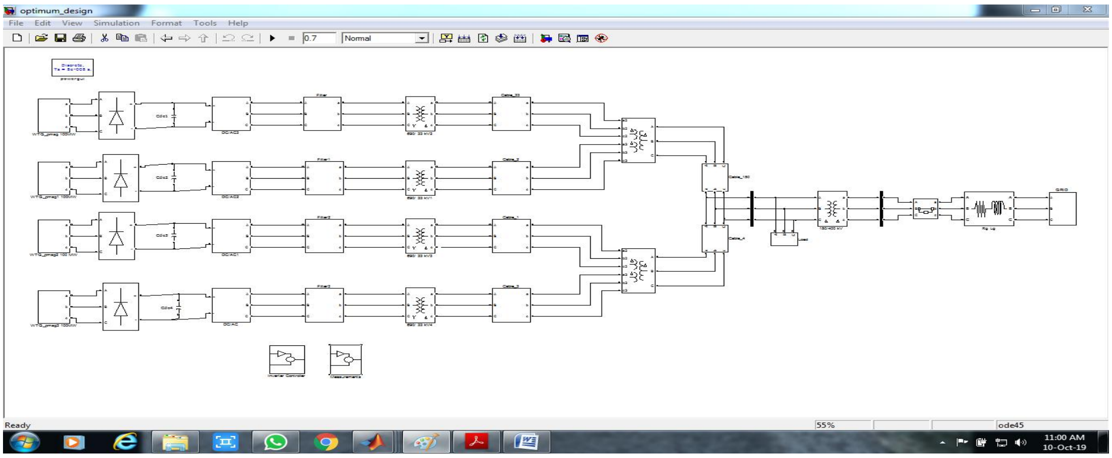


Fig:3. Dynamic response of GSC optimized design.

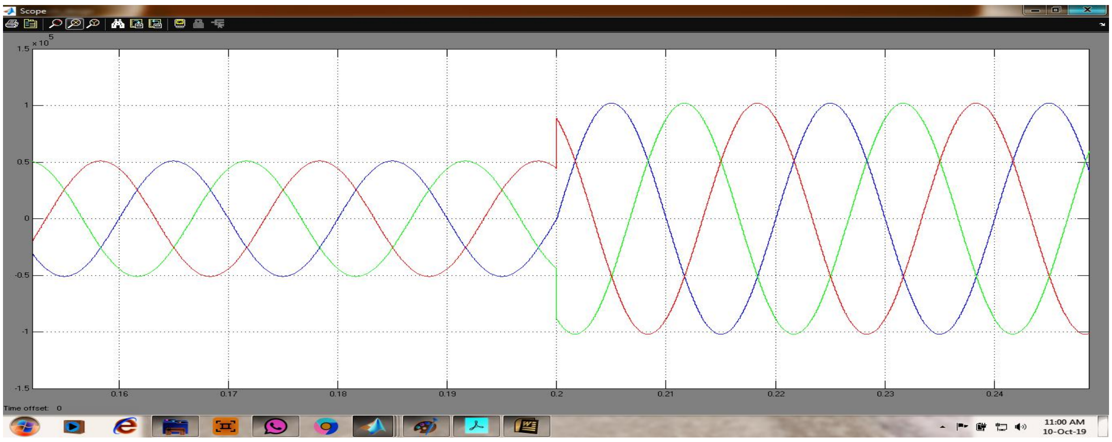


Fig:4. Step-response of the designed GSC for a strong grid.

Fig. 4 shows the step response of the GSC for a strong grid, where a desired dynamic response can be observed. The same controllers are used for all GSCs.

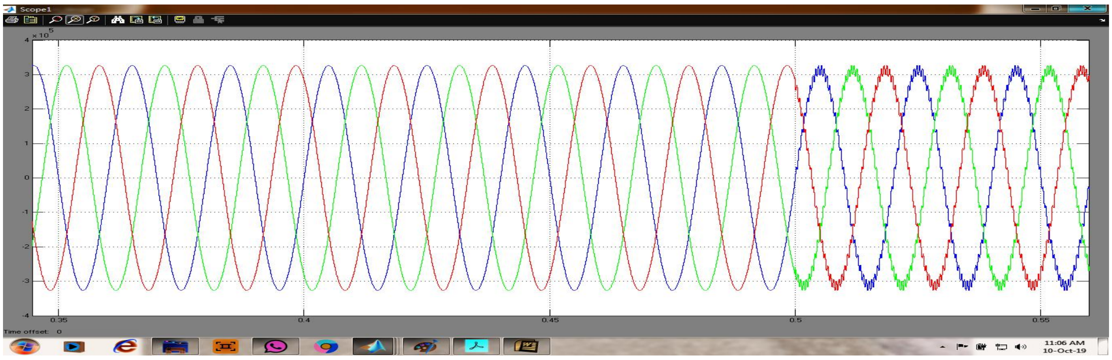


Fig:5(a)

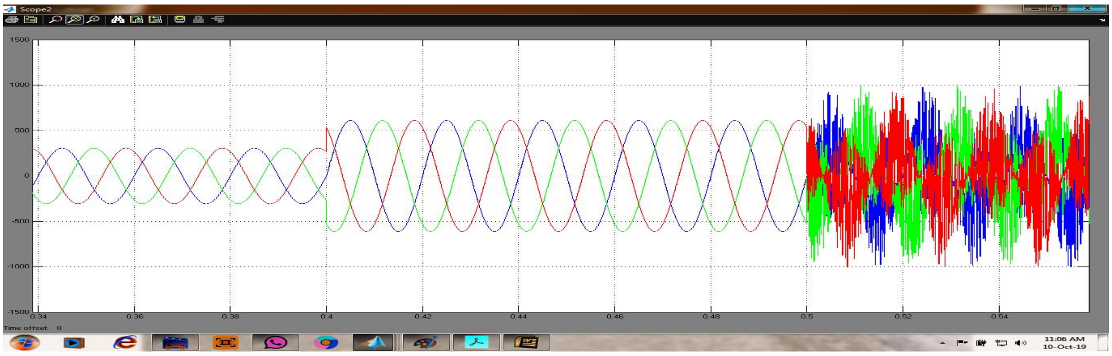


Fig:5(b)

Fig:5. Dynamic response of GSC. GSC parameters are changed from the optimum design to the initial design at $t = 0.5$ s and the dynamic response of the optimum design is also tested at $t = 0.4$ s. (a) PCC voltage, (b) gird current.

In Fig. 5, the wind farm is simulated in the time-domain using MATLAB software, where the current controller parameters of the GSCs have been set by the proposed optimum design (before $t = 0.5$ s). At $t = 0.4$ s, the current reference is changed from 0.25 p.u. to 1 p.u. As it can be seen, the wind farm has a good dynamic response and a stable operation for the optimized parameters. At $t = 0.5$, the GSC parameters are changed from the optimum design to the initial design. As shown in Fig. 5., some oscillations around 900 Hz propagate into the wind farm, because of the instability problems as predicted in the frequency domain. Therefore, it can be concluded that a good control design for an individual power converter cannot guarantee the stable operation of the whole power electronics based system as shown in Fig. 5..

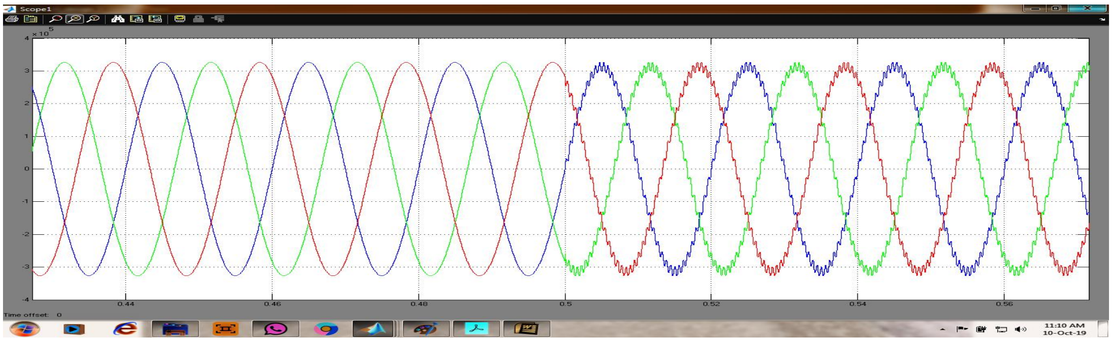


Fig:6(a)

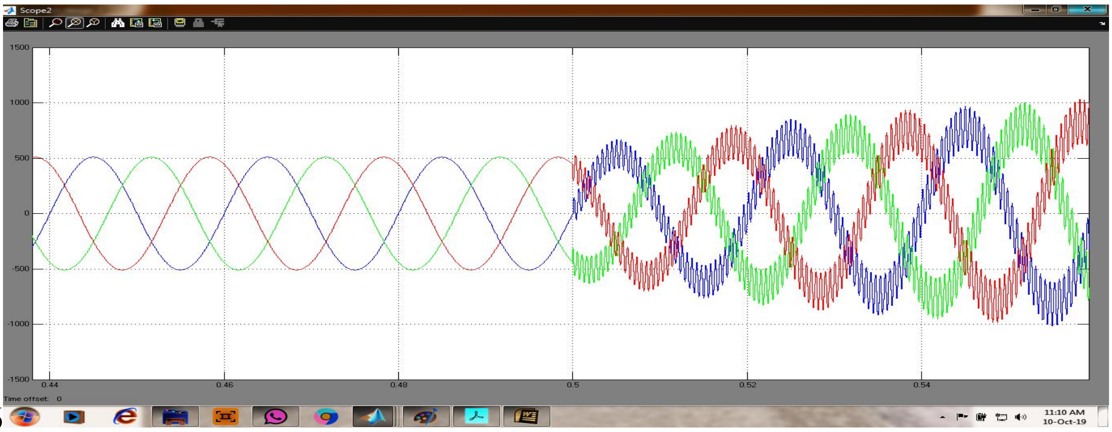
6 

Fig:6(b)

Fig:6 Robustness of the optimum design. (a) PCC voltage, (b) gird current.

By increasing the cable length, the capacitance and the inductance of the cable increase and the resonance frequency decreases. The damping of these poles corresponds to the resistance of the cable. As this resistance is very small, the damping of these poles is small. In order to confirm the robustness of the optimized design, the time-domain simulations have also been performed. First, the GSC parameters are optimized and set for SCR = 100 and Cable length = 10 km. However, the wind farm is simulated for another SCR and cable lengths, i.e., SCR = 50 and Cable length = 15 km. At $t = 0.5$, the parameters are changed to the initial design. As it can be seen from Fig. 10, the wind farm with the optimum controller design presents a robust and stable operation. However, after $t = 0.5$, the wind farm with the initial parameters is unstable and harmonic-frequency oscillations propagate into the grid.

IV. CONCLUSION

This paper presents a multi-objective design procedure for the power converter controllers in order to increase the stability margin in a power electronics based system. A power electronic system is introduced as a MIMO transfer function matrix and the oscillatory modes are identified by the determinant of the MIMO matrix. The proposed algorithm put the modes in the desired locations to improve the dynamic response of the system. A 400-MW wind farm is studied as a power electronics based system for the proposed optimum design procedure. Time-domain simulations confirm that a good design for an individual converter under strong grid cannot guarantee a stable operation of the whole power electronic system including many other converters and passive components. On the other hand, the proposed design technique is a powerful tool to analyze and to improve the dynamic performance of a large-scale power electronic system, such as a wind farm. In addition, the power electronic system with the optimum controller design shows a robust and stable operation against variations of the system.

REFERENCES

[1] B. K. Bose, "Global energy scenario and impact of power electronics in 21st century," *IEEE Trans. Ind. Electron.*, vol. 60, no. 7, pp. 2638–2651, Jul. 2013.

[2] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1398–1409, Oct. 2006.

[3] J. Liu, T. A. Nondahl, P. B. Schmidt, S. Royak, and T. M. Rowan, "Generalized stability control for open-loop operation of motor drives," *IEEETrans. Ind. Appl.*, vol. 53, no. 3, pp. 2517–2525, Jun. 2017.

[4] L. Wang, Z. H. Yang, X. Y. Lu, and A. V. Prokhorov, "Stability analysis of a hybrid multi-infeedHVdc system connected between two offshore wind farms and two power grids," *IEEE Trans. Ind. Appl.*, vol. 53, no. 3, pp. 1824–1833, Jun. 2017.

[5] Y. Guan, J. C. Vasquez, J. M. Guerrero, Y. Wang, and W. Feng, "Frequency stability of hierarchically controlled hybrid photovoltaic-batteryhydropowermicrogrids," *IEEE Trans. Ind. Appl.*, vol. 51, no. 6, pp. 4729– 4742, Dec. 2015.

[6] K. N. B. M. Hasan, K. Rauma, A. Luna, J. I. Candela, and P. Rodriguez, "Harmonic compensation analysis in offshore wind power plants using hybrid filters," *IEEE Trans. Ind. Appl.*, vol. 50, no. 3, pp. 2050–2060, Jun. 2014.

[7] C. F. Jensen, Ł. H. Kocewiak, and Z. Emin, "Amplification of harmonic background distortion in wind power plants with long high voltage connections," in *Proc. CIGRE Biennial Session*, Aug. 2016, Paper C4-112.

[8] C. Yoon, H. Bai, R. Beres, X.Wang, C. Bak, and F. Blaabjerg, "Harmonic stability assessment for multi-paralleled, grid-connected inverters," *IEEETrans. Sustain. Energy*, vol. 7, no. 4, pp. 1388–1397, Oct. 2016.

[9] A.Rygg, M. Molinas,C.Zhang, andX.Cai, "A modified sequence-domain impedance definition and its equivalence to the dq-domain impedance definition for the stability analysis of AC power electronic systems," *IEEETrans. Emerg. Sel. Topics Power Electron.*, vol. 4, no. 4, pp. 1383–1396, Dec. 2016.

[10] B. Badrzadeh,M.Gupta, N. Singh, A. Petersson, L. Max, andM.Høgdahl, "Power system harmonic analysis in wind power plants — Part I: Study methodology and techniques," in *Proc. IEEE Ind. Appl. Soc. Annu. Meeting*, 2012, pp. 1–11.

[11] N. Bottrell, M. Prodanovic, and T. C. Green, "Dynamic stability of a microgrid with an active load," *IEEE Trans. Power Electron.*, vol. 28, no. 11, pp. 5107–5119, Nov. 2013.

[12] A. Singh, and A. K. Kaviani, and B. Mirafzal, "On dynamic models and stability analysis of three-phase phasor PWM-based CSI for stand-alone applications," *IEEE Trans. Ind. Electron.*, vol. 62, no. 5, pp. 2698–2707, May 2015.

[13] L. P. Kunjumuhammed, B. C. Pal, C. Oates, and K. J. Dyke, "Electrical oscillations in wind farm systems: Analysis and insight based on detailed modeling," *IEEE Trans. Sustain. Energy*, vol. 7, no. 1, pp. 51–62, Jan. 2016.

[14] J. B. Kwon, X. Wang, F. Blaabjerg, C. L. Bak, A. R. Wood and N. R. Watson, "Harmonic instability analysis of a single-phase grid-connected converter using a harmonic state-space modeling method," *IEEE Trans.Ind. Appl.*, vol. 52, no. 5, pp. 4188–4200, Sep./Oct. 2016.

[15] A. Guha and G. Narayanan, "Small-signal stability analysis of an open loop induction motor drive including the effect of inverter dead time," *IEEETrans. Ind. Appl.*, vol. 52, no. 1, pp. 242–253, Feb. 2016.